Use of Geospatial Data and Models in Natural Resource Management

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GIS data: Advantages and limitations

During the last decade, there has been a proliferation of geospatial data in natural resource management including in the disciplines of forestry, fishery management, geology, geomorphology, hydrology, wildfire and climate change (Miller 2003, Wing and Bettinger 2008). Geographical information system (GIS) data and associated model output are only as good as the measurement technologies from which they are derived (e.g., aerial photographs, satellite imagery, laser altimetry, field surveys, digitizing, etc.). Important attributes about GIS data include their spatial (three dimensional) resolution (90 m, 10 m, and <10 m), accuracy, and precision. In addition, GIS information derived from predictive numerical models is also only as good as the model and the data that go into the model.

GIS data used in natural resource management can include hillslope gradients, aspects, stream networks, stream gradients, vegetation and other watershed features. In general, across the western U. S., 10-m digital elevation models (DEMs) are used within GIS-based numerical models to derive these and other watershed attributes such as slope stability, debris flow potential, and channel and fish habitat characteristics (Benda et al. 2007, Burnett et al. 2007). Forest growth models (FVS, Zelig, ORGANON) that use plot- scale field data are used to create predictions about stand structure over time. These model predictions, as well as others that use a single year's remote sensed data on stand structure, can be used to forecast the recruitment of wood to channels (using yet other models), and those predictions can be used to predict changes to fish habitat quality and abundance.

It is important to remember that GIS raster or cell-based data are relatively 'coarse grained' which means that data, such as vegetation type, is represented by square cells with sides of length, for example 90 m or 10 m with cell areas of 8100 m^2 or 100 m^2, respectively. These types of data are not accurate down to a more human scale of meters (e.g., while standing in the field); an exception is GIS information that utilizes sub-meter resolution LIDAR. Forest data at coarse scales are generalized, or averaged, and thus GIS information of forest structure will be only accurate in an averaged sense. Nevertheless, this type of coarse-grained information could be used effectively to plan timber harvest and or forest restoration activities across a large watershed over the next 50 years.

Another type of GIS information is vector (line) data such as stream channels that are derived either from digitizing paper (USGS) maps or from numerical models that use DEMs and roads (typically digitized from paper maps or aerial photographs). The accuracy of stream lines depends on the accuracy of the original map product (such as U.S.G.S. 1:24,000-scale topographic maps or the resolution of DEMs). If channel network extraction models are used

(Miller and Burnett 2007), the accuracy of the delineated channel network will be much better using 10-m versus 90-m digital elevation data. Similarly, the stream attributes so derived (e.g., gradient, floodplain width, orientation, etc.) will also depend on the DEM resolution and on the robustness of the numerical model itself. For example, if the delineated channel segments are 100 m in length, then the predicted channel gradients will be an average over that length scale.

The spatial accuracy of road lines is dependent on the care with which the locations of roads were digitized from maps or photos. The attributes that are extracted from roads, such as road gradients and drainage points, are also dependent on the digitizing accuracy.

Given the necessary coarse grain and, thus, approximate nature of most GIS data and numerical model predictions, **the relative difference among values** (whether grid cells, lines, points or polygons) **is likely more accurate compared to the absolute value of any single data point**. For instance, predictions of slope stability typically reveal a large range of failure potential across a watershed. The value of any site specific prediction (pixel scale) is only a rough approximation of reality (because of model limitations and uncertainty in governing parameters). The relative difference between areas of high and low instability, however, can provide a more accurate accounting of hillslope stability (or erosion potential) across a watershed and this type of knowledge is suitable for planning purposes.

Watershed- to landscape-scale GIS information about topography, stream networks, forest vegetation, erosion potential, and aquatic habitat has provided an unprecedented ability to consider entire watersheds (and landscapes) in the implementation of forestry and fishery management (Spies and Johnson 2007), and also to quantitatively forecast outcomes, including cumulative effects of forest practices (Dunne et al. 2001). Prior to advanced GIS, numerical models, and computer technology, this capability did not exist. Given the limitations of GIS information and associated numerical models, but also the advantages of these information systems, it is important to ask the following question: **How do resource managers and analysts apply geospatial data and models in their day-to-day work?**

GIS data and the resource manager

The obvious advantage of GIS for land use managers is its ability to provide spatial information at watershed and landscape scales and thus to provide the 'big picture' of where certain watershed attributes are located and how they relate (spatially) to other attributes (see www.netmaptools.org for numerous examples; Benda et al. 2007). For instance, where are the unstable hillslopes located and are they in close proximity to the best aquatic habitats? Where is the most fire prone vegetation located with respect to the most erosion prone soils, and where do these areas overlap with sensitive fish habitats? Which segments of roads are located on unstable ground, and if a failure occurs, could it enter a fish bearing stream? Thus, first and foremost, land managers use GIS information, analysis, and associated model predictions for screening (e.g., to get the big picture) and for watershed scale planning. For instance, when planning stream or road restoration, GIS maps of potential impacts of roads on aquatic habitats can be used to prioritize field surveys.

One key recommendation is that **as management plans built with GIS support are implemented, site-specific information (at the scale of an individual timber harvest plan or an individual stream reach restoration project) should be collected to fine tune management activities (or the projection of effects) in specific areas**, and thus plans should be adjusted as necessary. For example, **GIS information and analysis tools could be used to forecast forest growth and the effects of thinning on future forest stand structure, which affects shade from solar radiation and the amount and size distribution of wood in streams**. To offset the predicted reduction of wood in streams due to thinning in riparian areas, other models are used to forecast how trees directionally felled into streams will increase wood storage and hence improve fish habitats across entire watersheds. This type of GIS analysis can support the development of forest plans and their evaluation across entire watersheds. **When specific components of the management plan are implemented** (for example, thinning along a certain stretch of stream), then **a field reconnaissance or more detailed field measurements should be obtained to determine the exact structure of the forest stand to make more detailed site specific harvest (and tree felling) prescriptions at that site**. In other words, after the *planning stage* that utilized GIS information (and associated model forecasts), the *implementation phase* will require some type of validation step, that might include collecting site-specific information (on existing forest structure and aquatic habitat condition) to make adjustments as necessary to the management activities.

The same recommendation also applies to the use of GIS information in other activities involving riparian management, slope stability, road restoration, and wildfire risk assessment. Consider slope failure potential and the use of GIS information. Increasingly, management planning is taking place at the watershed scale (or at the scale of an entire national forest). Thus, there is a need to consider slope stability conditions at that scale to help guide placement of harvest units for a 10-year forest plan. First, we accept the premise that the application of one or more slope stability models utilizing 10-m DEMS provide acceptable results (Montgomery and Dietrich 1994, Miller and Burnett 2007). From a watershed scale perspective, a map of slope stability indicates where the unstable areas are located and their proximity to roads, stream channels, or high quality fish habitat. This information can be used to plan placement of new forest roads (or conversely locations where to abandon roads) and to plan forest harvest or forest restoration activities. In other words, **watershed-scale maps are important guides to watershed-scale forest management planning**.

How does GIS information, or associated modeling results about slope stability, get used in project specific planning? If geologists were asked to review or help design the placement of a forest road on a particular hillslope, the watershed-scale GIS maps would be very useful as a guide or screening tool, allowing them to see the big picture (e.g., the physical characteristics of a single hillslope compared to all the other surrounding hillslopes in the vicinity). **At the project level, more site-specific information is needed**. Is the hillslope sufficiently steep to be of concern (e.g., is the GIS information on slope gradient accurate)? Are there other instability features such as slope convergence, evidence of previous failures or ground cracking? What is the likelihood of a failure, and would the associated sediment would impact important resources, including sensitive fish habitats? **It is likely that the remotely sensed data and model predictions would match, approximately, what is found in the field**. However, attributes such as evidence of previous failures would not be included in model predictions, but they can help with a final determination.

Summary

For land use analysts and planners, it is important to understand the limits in accuracy and precision of GIS information, including data derived from remote sensing, field surveys, or digitizing, and from numerical models. Although GIS information is often approximate and coarse grained (particularly if derived from remote sensing and numerical model predictions), it offers unprecedented ability to plan (and evaluate through modeling) watershed-scale plans for forestry, restoration, road rehabilitation, conservation, wildfire planning, and to consider climate change impacts. For example, a GIS map of fish habitat quality can be used to prioritize where analysts will go into the field to plan inventory, monitoring, and restoration projects.

When implementing such plans at the scale of individual hillsides, stream reaches, or road segments (e.g., timber harvest, fuel treatments, forest restoration-thinning, placement of wood in streams for restoration, and road maintenance or abandonment), site-specific information should be obtained on the relevant parameters (e.g., forest stand condition, channel characteristics, hillslope conditions, and road attributes and conditions). Once field observations or data have been collected, site-specific management prescriptions can be tailored or modified as necessary from the original predictions made using GIS information. In that way, GIS information and field information are compatible, and when used together, they provide a robust method for implementing forest management or fishery management at scales ranging from the watershed down to the particular hillside, stream reach, or road segment.

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